**Problem Identification**

Diagram

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**Figure 1: The engineering design process showing problem definition as the start of the conceptual design process.**

Product development begins by determining what the needs are that a product must meet. Problem definition is the most important of the steps in the PDP (Fig. 1). Understanding any problem thoroughly is crucial to reaching an outstanding solution. This axiom holds for all kinds of problem solving, whether it be math problems, production problems, or design problems. In product design the ultimate test of a solution is meeting management’s goal in the marketplace, so it is vital to work hard to understand and provide what it is that the customer wants.

INTRODUCTION

If you were asked to design a corkscrew could you do it? Reference to Fig. 2, which illustrates many different types of corkscrew, probably convinces us that the answer to the question is yes. However, why are there so many fundamentally different types? How is it possible for different design teams to set out to design a corkscrew and end up with completely different devices?

In a little more detail the corkscrews illustrated in Fig. 2 are the plain corkscrew, with from left to right a double helix, lazy-tongs, the waiter's friend, a lever system and a screw pull. The double helix uses both left and right hand screws. One is inserted in the cork and the other forces the corkscrew against the neck of the bottle and removes the cork. The lazy-tongs illustrated provide a 4:1 mechanical advantage. Once the screw is inserted in the cork the handle is pulled and travels four times the distance that the cork travels thus reducing the force required. The waiter's friend provides a mechanical leverage which is dependent on the length of the handle. When the screw is inserted in the lever system the levers rise. As they are pressed down the cork is extracted by pushing against the neck of the bottle. In the final device the screw is simply inserted in the cork and the turning continued. The cork \*climbs' the screw.

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**Figure 2 Corkscrews**

All of the devices described rely on the screw to be inserted in the cork. They differ in the mechanical advantage provided, in appearance, in complexity and in production cost. In order that a satisfactory product is designed the market need must be thoroughly researched and a technical specification reflecting customer requirements developed. In the case of a corkscrew constraints such as the mechanical advantage required, the appearance and the production (ex-works) cost must be specified.

In the solution of any design problem the design process begins with the defining of the boundaries within which a solution must be found. The project brief as presented to the design team is often incomplete. Hence, research often needs to be conducted and information sought before a full Product Design Specification (PDS) can be produced. Even if a full PDS is provided it is the duty of the designer to question the validity of that PDS.

This questioning approach can often make a customer alter their requirements. As an example consider the problem which was set as one of designing a corkscrew. If the original problem statement had been to design a device for removing a cork from a bottle then many more solutions are possible. Figure 3 illustrates two devices for removing corks which do not use a screw, the wiggle and twist extractor and an air pump. In application the two prongs of the wiggle and twist extractor are inserted between the walls of the bottle and the cork. By careful combination of pulling and twisting the cork is removed. The air pump employs a hollow needle which is pushed through the cork. Subsequent pumping action increases the pressure behind the cork and the cork is pushed out. Both of these valid devices were ruled out by the thoughtless problem statement which dictated that a screw be used.

As a final thought on this problem it is interesting to consider the problem statement as to remove wine from a bottle. More importantly, the new problem statement is as intended from the outset. If this is the intention then removing the cork may only be one category of solution! As further emphasis of the importance of a clear problem statement consider two wonderful engineering achievements.

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**Figure 3 Cork extractors**

The two photographs. Figs 4 and 5 show what was until April 1998 the longest single span suspension bridge in the world, the Humber bridge, and Concorde (the only supersonic airliner in the world) respectively. Both are elegant and simple in form and each is a magnificent feat of engineering which must be seen to be believed. However, neither has made a profit for their owners!

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**Figure 4 Humber Bridge (Reproduced by kind permission of The Hunnber Bridge Board)**

A first draft of a PDS must be developed before any attempt is made at generating solutions to a problem. This is an important discipline since so much time, effort and money can be wasted by providing a solution to the wrong problem.

Whilst it is desirable that a fully defined PDS be written before the design process starts it must be recognized that for many projects this proves impossible. The design process is iterative and the PDS must be regarded as a fluid document which will develop along with the design. The PDS is questioned at all stages and reference made to the customer as and when changes are suggested by the design team. However, the aim at the outset is to define the PDS as fully as possible.

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**Figure 5 British Airways Concorde, the flagship of the world's civil aviation fleet (Reproduced with kind permission of British Airways)**

It is extremely important that prospective customers are identified and that the language used in the PDS can be readily understood. Even within engineering each discipline, mechanical, electrical, electronic, civil and chemical, has evolved a specialist code not readily understood by other engineers. The customer may be involved in a totally different profession and yet must be able to understand fully the PDS.

It is the duty of the design team to verify that every function and constraint specified is relevant, correct and realistic. Consequently, it is essential that a thorough investigation of the problem is made by the designer before a solution is sought. For large, complex and diverse problems it is generally worthwhile breaking the project down into smaller, more manageable, sections.

In general there are two main tasks which have to be completed if a thorough identification of the problem is to be achieved:

1. definition of the problem area;
2. formulation of the exact problem.

The exact formulation of the problem involves the writing of a comprehensive PDS defining all the required functions which the solution must provide and all the constraints within which the solution must work. The information necessary for addressing these two tasks may be known or could be determined by calculation, by testing and by information search. Wherever possible a questioning approach should be employed and questions should be phrased in such a manner that a specific or numerate response is demanded.

PDS CRITERIA

The main headings and criteria listed here and illustrated in Fig. 6 are intended to assist in the writing of the PDS. They are not to be regarded as an all embracing check-list which if followed blindly will completely define any PDS. Design projects are by their nature diverse and substantially different criteria are required from one project to the next. Nevertheless, the check-list will provide a good foundation upon which you, the student engineer can build. Once the project is begun you will find that many of the important criteria will suggest themselves. However, it is true that there is no substitute for

experience and you should always be prepared, at any stage of the design process, to ask for help and guidance from experts such as component suppliers.

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**Figure 6 PDS criteria**

The five main headings on Fig. 6, performance requirements, manufacture requirements, acceptance standards, disposal and operation requirements are now considered in detail.

Performance requirements

**Function(s)** There may only be a single main function which is to be provided by the product to be designed but this is unusual. More often than not multiple functions can be identified which can be divided into primary and secondary functions. These can vary in nature from mechanical, electrical, optical, thermal, magnetic and acoustic functions to name but a few. The primary function of an engine in a vehicle is to drive the wheels. Secondary functions, such as providing heating inside the vehicle and supporting alternators must also be listed.

**Loading** Loading can be divided into primary and consequential loading. Primary loads are due directly to the required function being provided. Shocks and vibration are generally consequent on the situation in which the product is used. Consequential loading is often very difficult to quantify without empirical data. Specified performance requirements should generally be met comfortably, with some performance to spare.

**Aesthetics** In some instances this is not important, particularly where the device or structure is not seen. However, for many consumer products or structures a pleasing elegant design is required and colour, shape, form and texture should be specified. All visible aspects must be in accordance with the nature of the product and reflect the corporate image of the company. Any statement in a specification which relates to the way a product will look is inevitably more qualitative than quantitative and should include analogy to qualities found in existing products or natural objects. It is possible to use techniques like golden section, which indicates that for aesthetic beauty any shape should be divided into two thirds and one third.

**Reliabitity** The required design life, taking due account of routine maintenance, must be specified. This is usually done by specifying the number of operating cycles rather than in units of time. Within this number of cycles an acceptable level (%) of random failures or breakdowns is also specified. Where high levels of life expectancy of components exist and it is known that those components will be employed in a controlled environment, such as in electronic circuits, it is common practice to specify the MTTF (Mean Time To Failure) and the MTBF (Mean Time Between Failures). Where reliability is critical, redundancy, either active or stand-by, should be specified. Reliability is inextricably linked with maintenance, even if a maintenance free product is envisaged.

**Environmental conditions** These include the temperature range, humidity range, pressure range, magnetic and chemical environmental conditions to which the product will be exposed. It is important to consider manufacture, store and transport environmental conditions along with the more obvious operating conditions. Also, any physical size restrictions should be specified. This is mainly dictated by the area available to the product when working but is often determined by considering transport and erection. The simplest form of expression for this constraint can be a diagram which forms an integral part of the PDS.

**Ex-works cost** Companies sell products for the maximum price the market will stand which often bears little relation to the cost of producing that product. Hence, the maximum cost specified in the PDS and which the design team must work to, should be the production (ex-works) cost and not the selling price.

**Ergonomics (Human factors)** If a product is intended for human use then account must be taken of the characteristics of those users. The design of the product and the tasks required of the product and the users must reflect their respective capabilities. The person/product interface, as identified in Fig. 7, must be carefully specified. Decisions are based on those functions which can be carried out by products and will vary as capabilities of machines increase. The functions carried out by the user are generally to sense a display, interpret it and make a decision and perform a controlling action.

The environment in which the product is to be operated should be specified carefully. For example, if noise levels are high then audible signals to which a user must respond may not be heard. Anthropometrics is the branch of ergonomics which deals with body measurements and it is normal to specify a user population who fall between the 5th and 95th percentile sizes in any particular respect. Any controls must operate in a logical or expected manner. Controls should be placed in easy reach of the operator.

**Quality** The quality of the product should meet market requirements and the quality of all components should be consistent. All workmanship must be in accordance with the best commercial practices. Robust design practices should be used where possible. All materials and components shall be new and free from defects.

**Weight** In some industries, such as aerospace, this is the most critical constraint. However, this is not always the case and weight is not always required to be a minimum. Generally in any product involving motion reduced weight is an advantage whereas a product where stability is critical may require weight to be a maximum. Minimum weight generally means less material which leads to reduced production costs and economic advantages.

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**Figure 7 Person/product task division**

**Noise** The upper limits of noise levels which can be emitted by the type of product being designed should be specified. Regulations differ from one country to the next so either the standard which applies in a particular country or the lowest maximum limit amongst those countries targeted for export must be specified. These standards represent the maximum level of noise which is acceptable but lower levels could be specified, for example, to gain competitive advantage.

Manufacture requirements

**Processes** The in-house manufacturing and forming facilities and the criteria under which external resources are sought should be specified. The required reliability of any source of supply and the required quality should be specified. Any special finishing processes which may be required should also be specified.

**Materials** Materials for both the product and its packaging must be considered and the criteria governing the selection of materials specified without constraining the design team unnecessarily. The many criteria which must be considered are corrosion and wear resistance, flammability, density, hardness, texture, colour, aesthetics and recyclability. There are also many regulations governing the use of hazardous materials which must be included in the specification if relevant.

**Assembly** The method of assembly should be specified; automatic, manual or assembly line. The rate of feed of components for assembly and time allowed are also important parameters. The specification should also contain statements with regard to the ease of disassembly.

**Packing and shipment** The maximum size and weight for convenient transportation must be specified. Shape can also be important since stacking products together can reduce transport costs substantially. Provision of suitable packing, lifting points and locking or clamping of delicate assemblies should be specified to prevent damage during transport. It may also be important to ensure large products can be disassembled and reassembled easily for transport. The cost of packing and shipment must be added to the ex-works cost to ensure that the product remains competitive wherever it is used.

**Quantity** The projected quantity of a product which will be sold can have a profound effect on the manufacturing methods and materials used. This must be specified as carefully as possible at the outset. This particularly influences the appropriate levels of tooling, with large quantities justifying expensive tooling.

**Delivery date** It is important that realistic timescales are set for each stage of the design and production process. This is particularly important when a delivery date has been agreed with a customer and costly penalties for late delivery are built into the contract. Hence, the date by which each stage of the process is to be completed must be specified at the outset. The PDS of a single complex system which is to be designed and produced to an agreed contract will state dates by which the design, manufacture, erection, testing, commissioning and hand over of the fully working installation are to be completed.

Acceptance standards

**Inspection** The degree of conformance to standards must be specified in accordance with relevant legislation and the objectives set in the PDS. The degree of conformance required to tolerances as stated within the rest of the specification must also be specified.

**Testing** The methods of verification for the product should be specified along with the timescales for carrying out the necessary tests. It is usual on completion that acceptance tests are carried out in the presence of the customer. Tests often include safety interlocks, load capabilities such as speed and power consumption and reliability. Specified means and forms of testing should comply with standards where they exist. The PDS should contain a policy statement on the level of testing, such as every product to be tested or an agreed level of sample testing.

**Standards** These may include national, international and company standards. There may also be many other rules, regulations and codes of practice which must be followed.

**Patents** Following a patent search it is important to state, and subsequently to ensure, that the design must not infringe any patents identified as being relevant. Patents are useful sources of information, particularly when you are beginning a new project with no previous experience in the particular field.

Disposal

**Standards** Individual country or international standards for disposal of products and materials must be listed in the PDS. The main implications should be stated. For example, most plastic materials used now must be identified during moulding of the component so that recycling and more importantly, reuse is made possible.

**Legislation** Any legislation governing the disposal of a product must be specified. Many governments are tightening their legislation with a view to ensuring recycling takes precedence over other methods of disposal, that manufacturers are responsible for accepting products from their last owners and that ease of dismantling and disposal are specified from the start. Also, legislation dictates that all materials used can be easily identified for subsequent recycling or disposal at the end of the life of the product. This

must be specified.

**Company policy** Products which make less impact on the environment than similar products will have an increasing marketing advantage. They also afford a company significant advertising opportunities, which will also improve their competitive position. There are many ways of specifying this and only one is to specify increased life.

**Hazards** Any potential hazards that may cause difficulties at the end of a product's life should be identified and specified.

Operation requirements

**Installation** Where installation of a product is complex it should be specified. This is particularly important when small numbers of large devices are designed. The constraints should include construction, assembly, the time taken, provision of instructions and the skill levels required for installation.

**Use** The cost of ownership of a product, which should be minimized, is, in some cases, more important than the cost of initial purchase. Factors which influence this, such as the number of operators required, the skill level required from these operators, the cost of spares and the maximum tolerable energy consumption should be specified. Continuous, 24 hour a day, operation or the number of stop/starts in a relevant timescale should be specified. An alternative to dividing costs into separate categories is to specify a whole-life cost.

The power sources available should also be specified. These may include manual, gravitational, environmental, electrical, gas, water and internal combustion engines. Each should be specified exactly. For example, electrical power may be three-phase and 380-420 volts.

**Maintenance** A policy to minimize down time, simplify maintenance, ensure correct reassembly, provide easy access and provide interchangeable parts must be developed at the outset and specified. If there is to be any routine maintenance, service or overhauls the intervals and complexity of these should be specified. In order to simplify the maintenance procedure provision of special purpose tools and disassembly features should be specified if appropriate. The required skill levels of maintenance staff should also be specified. Guards should be easily removed. Levels of lubrication should be specified. An operation and maintenance manual must be supplied. Automatic lubrication should be considered.

**Safety** There are many standards, a great deal of legislation and codes of practice which refer to all safety aspects of products. These should be listed in the PDS. As an example consider Fig. 8, which is extracted from British Standard 3042 and shows test finger IV. This is one of a series of probing devices for checking protection against mechanical, electrical and thermal hazards. Where standards do not exist it is normal to specify fail safe design with no sharp edges and that electrical panel isolators must be interlocked with the door, for example. Where headroom over walkways is less than 2m suitable warning notices and head shock absorbers should be provided. Guards should be specified to eliminate danger to individuals or equipment.

Diagram, engineering drawing

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**Figure 8 Test finger IV. From British Standard 3042:1971 (Extracts from BS 3042:1971 are reproduced with the permission of BSI under licence no. PD\1998 1956. Complete editions of the standards can be obtained by post from BSI Customer Services, 389 Chiswick High Road, London, W4 4AL)**